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Safety assessment of electromagnetic radiation from mobile phone antennas to the human head

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Abstract: In order to explore the influence of mobile phone antenna electromagnetic radiation on the human head, a simulation system including a multi-antenna mobile phone model and a human head model was constructed using COMSOL simulation software. The specific absorption rate (SAR) of mobile phone electromagnetic radiation on the human head is calculated by finite element method at two different operating frequencies. The results show that the SAR values calculated by all the simulations are lower than the limits stipulated by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), indicating that the electromagnetic radiation generated by the mobile phone antenna on the human head is safe.

Keywords: Electromagnetic radiation; Specific absorption rate; Finite element method; Electromagnetic simulation model.

1. Introduction

With the widespread use of smart phones, people are paying more and more attention to the impact of mobile phones on human health. Obviously, in addition to the convenience that mobile phones provide to public life, the electromagnetic radiation produced by mobile phones has also become a part that cannot be ignored. The impact of electromagnetic radiation on human health, especially the impact on the health of the human head, has become the focus of attention of the public and major operators [1-3]. The types of electromagnetic radiation from mobile phones include electromagnetic radiation, thermal radiation, non-ionizing radiation, and ionizing radiation. Among these types, electromagnetic radiation is the most important one, and it is also the most concerned one. Electromagnetic radiation is mainly composed of radio waves and microwave radiation. The composition is a kind of high-frequency electromagnetic radiation. The electromagnetic radiation generated by mobile phones refers to the radiation generated during the transmission of electromagnetic waves emitted by mobile phones. In the process of mobile phone electromagnetic radiation, the impact mainly comes from the call. The process of the call is that when the mobile phone is used for real-time communication, radio waves will be emitted from the mobile phone. These radio waves of radio frequency energy received by the communication base station the electromagnetic signal is transmitted to the switching station, and then the signal will be transferred to other base stations or mobile phone networks. When the microwave radiation value of the radio wave generated in the process will be higher than a certain limit value, it will be affected human health [4].

Although the current research results do not clearly show that mobile phone radiation is harmful to human health, governments and organizations in various countries are still formulating relevant standards and recommendations to ensure public safety. For example, the US Federal Communications Commission (FCC) stipulates that the radiation intensity of electromagnetic radiation from mobile phones must not exceed the maximum value absorbed per gram of head tissue (1.6 W/kg), and the ICNIRP standard is no more than 2W/kg. In addition, individuals should also minimize the time spent in contact with mobile phones for a long time to avoid unnecessary impact on their own health. Therefore, with the continuous development of science and technology, the impact on mobile phone radiation also needs to be continuously studied and evaluated in order to better protect people's health and safety. In terms of the measurement of mobile phone electromagnetic radiation, international standards [5, 6] The measurement method of the specific absorption rate of the mobile phone to the human body is specified [7-11]. Due to the high time cost and economic cost of the SAR test of the mobile phone, it is imperative to use the simulation method on the computer to simulate the electromagnetic radiation of the mobile phone to the human body.

2. Electromagnetic simulation simulation calculation method

The finite element method (Finite element method, FEM) is a numerical calculation method with high precision and high reliability. It has a good effect on the numerical calculation of electromagnetic radiation from mobile phones to the human head. The basic principles of the finite element method are outlined below. The established simulation model of mobile phone electromagnetic radiation to the human body is aimed at the three-dimensional electromagnetic field. Next, I will take the three-dimensional edge finite element method as an example to illustrate its principle. The Maxwell equation is the embodiment of the universal law of the electromagnetic field. It determines the nature, characteristics and how to change the electromagnetic field. It has both differential and integral forms. If the change of the electromagnetic field is periodic, the mathematics can be simplified by using complex quantities Analysis, the expression of the periodic electromagnetic field in the differential form of Maxwell equations is the time harmonic field expression:

$$\begin{cases} \nabla \times \overrightarrow{\boldsymbol{H}} = \boldsymbol{j}\omega \overrightarrow{\boldsymbol{D}} + \overrightarrow{\boldsymbol{J}} \\ \nabla \times \overrightarrow{\boldsymbol{E}} = -\boldsymbol{j}\omega \overrightarrow{\boldsymbol{B}} \\ \nabla \cdot \overrightarrow{\boldsymbol{D}} = \rho \\ \nabla \cdot \overrightarrow{\boldsymbol{B}} = 0 \end{cases} \tag{1}$$

In the above expression, H is the magnetic field intensity vector, J is the current density vector, D is the electric displacement, E is the electric field intensity vector, B is the magnetic induction intensity vector, and ρ is the free charge body density. In order to determine the unknowns in Maxwell's equations, it is necessary to use the constitutive equation of the medium. In an isotropic linear medium, the constitutive equation is necessary, and the constitutive equation is as follows:

$$\begin{cases} \boldsymbol{B} = \mu_0 \mu_{\boldsymbol{r}} \boldsymbol{H} \\ \boldsymbol{D} = \varepsilon_0 \varepsilon_{\boldsymbol{r}} \boldsymbol{E} \\ \boldsymbol{J} = \sigma \boldsymbol{E} \end{cases} \tag{2}$$

$\mu_0$and$\varepsilon_0$are the permeability and permittivity in vacuum, respectively; μ_r and ε_r are the relative permeability and relative permittivity of the medium, respectively; σ is the conductivity of the medium.

2.1. Three-dimensional governing equations

The first three equations in Maxwell's equations (1) can describe the electromagnetic field independently, but they cannot be solved independently because they contain both electric field strength and magnetic field strength. Through the constitutive equation, the electric field strength E and the magnetic field strength H can be eliminated, so as to obtain a second-order differential equation containing only one unknown quantity:

$$\nabla \times \left(\frac{1}{\mu} \nabla \times \boldsymbol{E} \right) - \omega^2 \varepsilon_{\boldsymbol{c}} \boldsymbol{E} = -\boldsymbol{j}\omega \boldsymbol{J}_{\boldsymbol{i}} \tag{3}$$

$$\nabla \times \left(\frac{1}{\mu} \nabla \times \boldsymbol{H} \right) - \omega^2 \mu \boldsymbol{H} = \nabla \times \left(\frac{1}{\varepsilon_c} \boldsymbol{J}_{\boldsymbol{i}} \right) \tag{4}$$

$\boldsymbol{J}_{\boldsymbol{i}}$ is the external current or the source input current, and $\varepsilon_{\boldsymbol{c}} = \varepsilon - \frac{\boldsymbol{j}\sigma}{\omega}$ is the joint action of the induced current and the displacement current? The above two formulas are also called the vector wave equation, also known as the vector Helmboltz equation in the ordinary differential equation. From theoretical analysis, the governing equations of 3D electromagnetic field problems are generally 3D Maxwell equations, but in the actual calculation process, most of the above-mentioned vector Helmboltz equations are used as the governing equations, which is more convenient for modeling and solving.

2.2. Three-dimensional variational formula

In order to better explain the problem, we take the electric field intensity wave equation in the passive area as an example, which is the governing equation of this area, and the formula is as follows:

$$\nabla \times \left(\frac{1}{\mu_{\boldsymbol{r}}} \nabla \times \boldsymbol{E} \right) - \boldsymbol{k}_0^2 \varepsilon_{\boldsymbol{r}} \boldsymbol{E} = 0 \tag{5}$$

$\mu_{\boldsymbol{r}}$ is the complex relative permeability, $\varepsilon_{\boldsymbol{r}}$ is the complex relative permittivity, and $\boldsymbol{k}_0 = \omega\sqrt{\mu_0 \varepsilon_0}$ is the wave propagation constant in free space. By applying the variational principle to vary the above formula, we can get the corresponding functional as:

$$\mathrm{R}(\boldsymbol{E}) = \iiint_{\Omega} \left\{ \frac{1}{\mu_r} (\nabla \times \boldsymbol{E}) \cdot (\nabla \times \boldsymbol{E}) - \boldsymbol{k}_0^2 \varepsilon_r \boldsymbol{E} \cdot \boldsymbol{E} \right\} \boldsymbol{d}\Omega \tag{6}$$

2.3. Tetrahedral unit

The core of the finite element method lies in discrete segmentation and element interpolation. For three-dimensional problems, the commonly used discrete elements are rectangles, tetrahedrons, and hexahedrons. However, in general, the speed, accuracy and memory requirements of discrete elements for finite element calculations in different dimensional problems are different. However, in problems of different dimensions, the speed, accuracy and memory requirements of discrete elements for finite element calculations are different. The one-dimensional tetrahedron element is the most basic discrete element in three-dimensional space. However, the linear system of the traditional finite element tetrahedron element may have problems such as interface discontinuity, false solutions, and singularities when solving harmonic electromagnetic field problems. The edge element element (also known as vector finite element) shown in Figure1 has become a method to solve such problems.

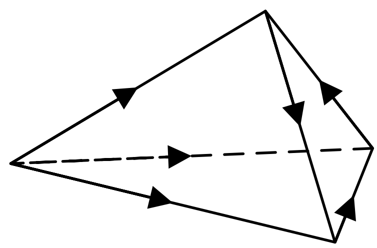


Figure 1. Tetrahedron element and edge definition

The following formula can be used to approximately calculate the electric field vector at different positions in the tetrahedral element:

$$\boldsymbol{E}^{\boldsymbol{e}} = \sum_{\boldsymbol{i}=1}^{6} \boldsymbol{N}_{\boldsymbol{i}}^{\boldsymbol{e}} \boldsymbol{E}_{\boldsymbol{i}}^{\boldsymbol{e}} \tag{7}$$

2.4. The discretized functional

The division of tetrahedral elements can be used to discretize and solve the area integral, which makes the calculation simpler and more feasible, that is, for each tetrahedral element, the integrand in equation (6) can be used in equation (7) Instead, get an integral expression that contains only the independent variable within the cell, and then multiply it by the volume of the cell to get the integral value within the cell. Finally, the integral value of the entire area can be obtained by adding the integral values of all tetrahedral elements:

$$\boldsymbol{R}(\boldsymbol{E}) = \frac{1}{2} \sum_{\boldsymbol{e}=1}^{\boldsymbol{m}} \left(\left\{ \boldsymbol{E}^{\boldsymbol{e}} \right\}^{\boldsymbol{T}} \left[\boldsymbol{A}^{\boldsymbol{e}} \right] \left\{ \boldsymbol{E}^{\boldsymbol{e}} \right\} - \boldsymbol{k}_0^2 \left\{ \boldsymbol{E}^{\boldsymbol{e}} \right\}^{\boldsymbol{T}} \left[\boldsymbol{B}^{\boldsymbol{e}} \right] \left\{ \boldsymbol{E}^{\boldsymbol{e}} \right\} \right) \tag{8}$$

m is the total number of subdivision units.

$$\left[A_{ij}^e\right] = \iiint \frac{1}{\mu_r}\left\{\nabla \times N_i^e\right\} \cdot \left\{\nabla \times N_j^e\right\}^T dV \quad (9)$$

$$\left[B_{ij}^e\right] = \iiint \varepsilon_r^e \left\{N_i^e\right\} \cdot \left\{N_j^e\right\}^T dV \quad (10)$$

By calculating the value of the sum, the final matrix equation can be obtained, and the calculation formula of each element in the matrix can be further deduced. Specifically, according to the discretization idea of the linear finite element method, the area to be solved is divided into several units, and the partial differential equations inside each unit can be expressed as a linear equation system. By assembling these linear equation systems, the system of linear equations for the entire region can be obtained. Among them, each element in the coefficient matrix of the linear equation system can be expressed as the sum of element contributions, that is, the sum of the corresponding element in the stiffness matrix of each element multiplied by the proportion of the element in the total volume. Each element in the right-hand vector of the coefficient matrix can also be obtained by multiplying the element stiffness matrix with the corresponding load vector of the element and summing their proportions in the total volume. Therefore, by calculating the contribution of each unit, the coefficient matrix of the entire area and the calculation formula of the right end vector can be obtained, so as to obtain the final matrix equation. Therefore, this paper uses this method to estimate the SAR value of mobile phone electromagnetic radiation on the human head.

3. Simulation calculation of electromagnetic simulation model

In this paper, the antenna model shown in Figure 2 is used to analyze the electromagnetic wave reflection ability of each port of the antenna, which is helpful for a deeper understanding of the performance of the antenna. Due to the complex working environment, its VSWR usually needs to be controlled below 2.5, reaching below 2 then works best. The standing wave ratios of the two antenna modules proposed in this paper are all within 2, and the input impedance of the antenna is 50Ω, which can meet the electromagnetic simulation at two frequencies.

Figure 2. Mobile phone antenna model

After combining the human head model, the overall electromagnetic simulation model can be established as shown in Figure 3.

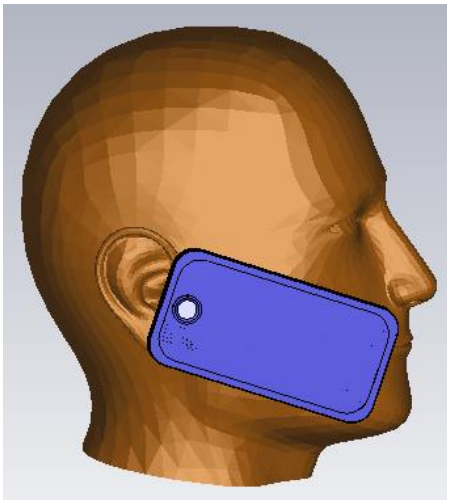


Figure 3. Whole Electromagnetic Simulation Model

Using the finite element method, the electromagnetic simulation model is meshed, and the results in Figure 4 are obtained.

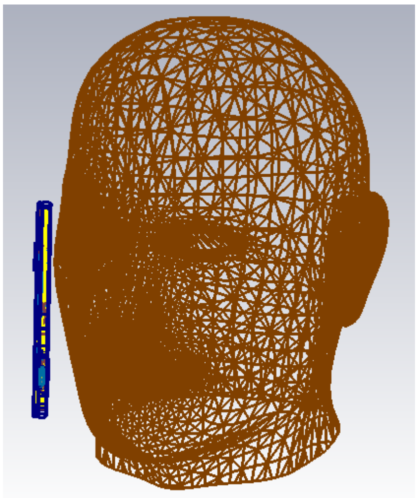
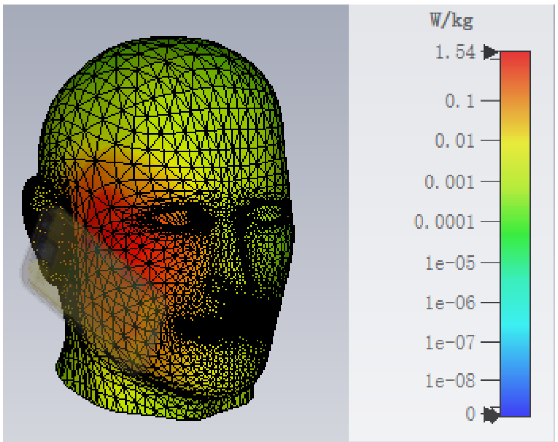


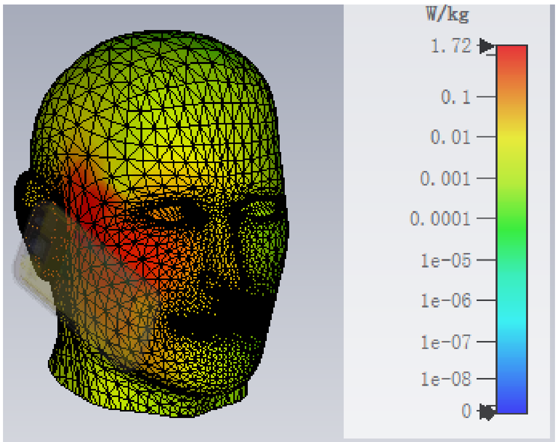
Figure 4. Mesh diagram

According to the electromagnetic simulation model constructed, the simulation calculation of the electromagnetic radiation of the mobile phone to the human head is carried out, and the obtained results are shown in Figure 5.

From the simulation results obtained by the simulation, the result of the SAR value at 900MHz is 1.54W/kg, the result of the SAR value at 2300MHz is 1.72W/kg. After comparing with the control limit of ICNIRP standard, it is obtained that the SAR value of the mobile phone to the electromagnetic radiation of the human body in this paper is below the safety limit of the electromagnetic environment of the human body.



(a)



(b)

Figure 5. Electromagnetic simulation SAR value results at different frequencies(a)900Mhz(b)2300MHz

4. Conclusion

This paper calculates the SAR value of the electromagnetic radiation of the mobile phone to the human head, introduces the electromagnetic simulation calculation method, including the basic principles and steps of the finite element method, and uses the electromagnetic simulation software COMSOL to construct the electromagnetic simulation model of the mobile phone and the human head , so that the finite element method and the model are used to obtain the SAR value of mobile phone radiation acting on the human head at different frequencies. After comparison with the ICNIRP standard, the SAR value is below the safety limit of the human electromagnetic environment. In order to measure the electromagnetic radiation of mobile phones positive effects on human health.

Acknowledgments

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